Choke Coils - Filter Systems and Voltage Dividers

LESSON ND-20

SPRAYBERRY ACADEMY of RADIO

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CHOKE COILS - FILTER SYSTEMS AND VOLTAGE DIVIDERS

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Since Michael Faraday discovered electromagnetic induction in 1831, and Gibbs developed the transformer in 1882, it has become more useful each year. With your knowledge of the basic principles on which a transformer operates, you are ready to learn how to use the power it develops. In an earlier lesson you studied rectifiers. With the study of this lesson, you will have completed the basic *power supply* components. Even though it is possible to step-up or step-down A. C. and rectify it, this knowledge would be useless unless the principles of *filtering* and smoothing and regulating the D. C. were well understood.

In a previous lesson, it was stated that *filter choke coils* with large value *filter condensers* were used to remove the rectified ripple voltage from the output of a rectifier. In this lesson, you will study each of the parts of a *filter* system and their relation to each other in comprising a complete filter network. One important part of such a system is the *iron core filter choke.*

IRON CORE FILTER CHOKE

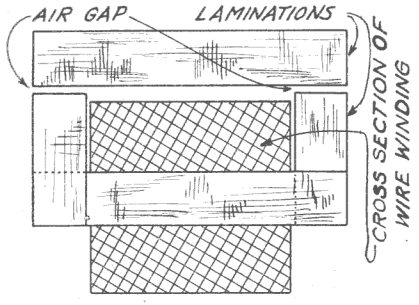
It is possible, but not practical, to use a choke coil without an iron core. The large size of such a coil makes it impractical. It is much more economical to wind the coil on a metal core similar to those used in transformer laminations. Figure 1 shows such a choke coil. Note the air gap. In a transformer the laminations would be so stacked or placed together that this gap would be eliminated. In a choke, however, the air gap is deliberately arranged. More about the air gap later in this lesson.

In addition to the core being standard, the coils and insulation are wound and placed the same way as in transformer construction. However, due to the fact that most chokes handle high voltages, the insulation used must be of high quality.

The shell type of choke coil construction is shown in Fig. 2. Here again you may note the use of the E type lamination. Air gaps are provided in each of the legs of the core so as to interrupt the magnetic circuit. A typical choke coil is shown in Fig. 3. This illustrates a coil *before* it is placed on its core. Such a winding is similar to those used in transformers but may usually be identified by the fact that a choke coil has only one winding where a transformer usually has several.

A coil or winding made for a choke is wound with wire large enough to safely carry the value of current which is expected to flow. Other considerations are the *inductance* required and the D. C. *voltage drop* to be allowed.

Iron core choke coils are also known as retard coils and, more often, as *reactors.*

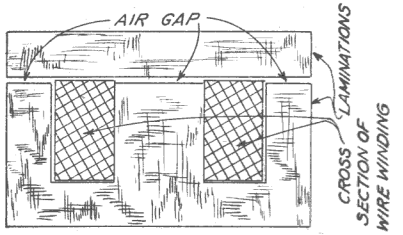


CLOSED CORE TYPE OF CHOKE COIL CONSTRUCTION

FIG. 1

THE AIR GAP

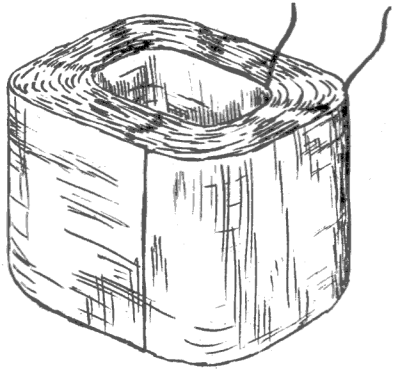
The purpose of an iron core choke coil in a power supply filter circuit is to prevent or oppose current changes. It will not prevent these changes completely, but it has a tendency to do so. As you have studied before, the inertia effect of inductance tends to hold back the flow of current; then, after a current is flowing, it has the tendency to continue the flow due to the collapsing magnetic field surrounding the coil. Since the current from a rectifier is varying, there will be a varying current through the choke coil. This current through the choke is composed of A.C. and D.C. When the total current through the choke increases to a point which is above the choke's point of saturation, the *permeability* of the core and *inductance* of the winding begin to reduce, and the choke will be overloaded.



SHELL TYPE OF CORE CONSTRUCTION

FIG. 2

You have already learned that above the point of saturation an increase in current flow will no longer produce a proportional increase in magnetism. This, in turn, will result in a lowering of the inductance of the winding. In the case of an overloaded choke, when the A. C. peaks go above the point of saturation, they will be allowed to pass with very little opposition. In other words, there will be little, if any, choking action on that part of the current which is in excess of that amount required to produce saturation. As has been mentioned, it is possible to wind a choke coil large enough to prevent saturation with any given amount of current. However, due to the large quantity of wire and the physical size of the choke, this would be both costly and impractical. An *air* gap in the core's magnetic circuit provides an economical method of producing a small choke of reasonable electrical capabilities. Such an air gap is shown



CHOKE COIL WIRE WINDING

FIG. 3

in Figs. 1 and 2. *This air gap is usually filled with a non-magnetic insulating material such as bakelite or a wax impregnated canvas.* Conductive non-magnetic materials, such as brass or lead, should not be used since these would tend to increase the eddy current loss. The air gap space usually varies between .005 and .01 inch, depending on the value of the current flow, the desired inductance, etc.

Since the air gap interrupts the magnetic circuit, the core's reluctance is increased. This is analogous to placing resistance in series with an electrical circuit. If resistance is added to an electrical circuit, it is necessary to increase the voltage to cause the same amount of current to flow as before. The original current value in this electrical circuit is comparable to the saturation point in a magnetic circuit. By adding resistance, more voltage must be applied to permit the same current flow. A similar action may be produced in the magnetic circuit by adding an air gap and, therefore, adding reluctance to the magnetic circuit. Thus a higher value of magnetomotive force may be impressed. This has the effect of reducing the flux density and increases the point of saturation to a new higher value before the saturation point is again reached.

From this you can see that a choke with an air gap will, as far as A. C. is concerned, exhibit a greater self-inductance than will the same size choke with no air gap. The ability of a choke to induce a counter EMF determines its value in a filter circuit. If large rectified ripple voltage peaks do not saturate its core, then the choke is still as effective on the peaks as it is on lower values of voltage. If, however, the rectified peaks saturate the core, then the *self-inductance* decreases for current value above saturation. A choke has little effect on smoothing out the peaks which occur above saturation. Therefore, these peaks pass through the filter circuit as ripple voltage, and hence the power supply does not supply a hum free voltage to the plates of the tubes in the receiver or amplifier.

This problem, if present in a radio receiver or amplifier, could be overcome by using a choke of higher inductance or by using one which did not saturate at the normal current which was to be supplied.

In Fig. 4 is shown the difference between chokes with and without air gaps. The two curves shown represent the action of two identical chokes, the only difference being that one has an air gap while the other has a continuous magnetic circuit. For values of current below 35 milliamperes, the non-air gap choke has a much greater inductance than does the choke with an air gap. For low values of current, the non-air gap choke is more efficient. Because, in power supply work, high values of current are important, a very *much* larger non-air gap choke would be required for the conditions illustrated in Fig. 4. Such a choke would be more expensive to build and would be large in size. For high values of current, the non-air gap choke would be impractical for ordinary radio apparatus. The air gap

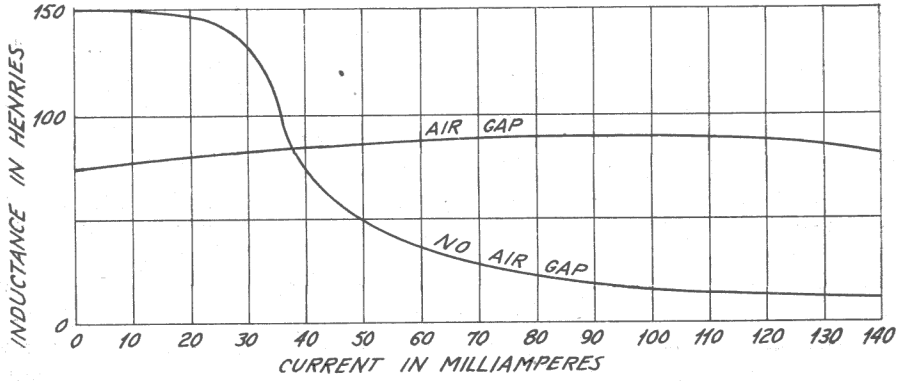


FIG. 4

choke, as you will note in Fig. 4, has a comparatively low value of inductance at low current values. Above 35 milliamperes, its inductance changes little for values up to 110 milliamperes, which may be assumed to be the point of saturation. It is seen that the non-air gap choke saturates at 35 milliamperes, and, since in power supplies the current value is relatively high, it may be seen that the air gap choke is not only more efficient but economical as well.

Here a word of caution. When choosing a choke, always be certain that its inductance rating is given while passing the current required for the filter system in which it is to be used. Too often a choke is used as being of a certain inductance without regard to the current it is to pass. The result is that the choke is operated in a saturated condition with a resultant hum in the output of the filter system.

It is necessary that a choke, to operate efficiently, must *not* have more than a certain amount of *direct* current flowing through it. This amount must be limited to the point which still allows the A.C. component to affect the coil without saturation.

Thus, a choke coil may be rated at 15 henries, 150 ma., 210 ohms. This means it will have an inductance of 15 henries if the direct current through it does not exceed 150 milliamperes and that its D.C. resistance is 210 ohms.

Often a choke will be made in two sections or what is termed a tapped choke. The reasons for this will be described later in this lesson. Perhaps the most common type of choke is the *speaker field coil* which, as you know, supplies the magnetism for the voice coil of a dynamic type speaker. The air gap in the speaker field choke is across the opening, or orifice, in which the voice coil moves.

FILTER CONDENSERS

In a previous lesson you studied the general function of a filter circuit. Its purpose is to *smooth* the ripple present in the output of a rectifier, provide good regulation of the rectified voltage and supply several different voltages as distributed by a voltage divider. You have studied rectifiers and power transformers; thus you know that the output of the filter is fed to the

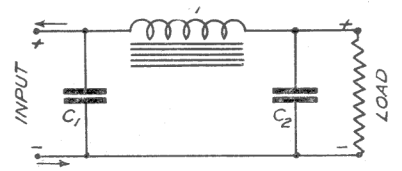


FIG. 5

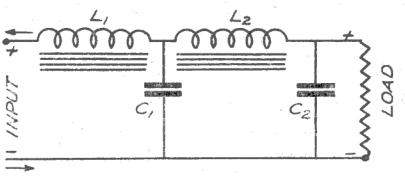


FIG. 6

load. For the purpose of further study, the filter circuit will be shown, as in Figs. 5 and 6, with two open terminals to which the output of the rectifier would be fed. The arrows in Figs. 5 and 6 indicate the direction of the D. C. flow, thus conforming with the electron theory of current flow. The load is represented by a unit resistor although you should understand that the real load may be made up of several resistors or tube circuits as will be explained later on under voltage dividers.

Although you have studied filter condensers in other SAR lessons, a short review of their function will be presented here.

In the early days of radio it was the practice to use paper type condensers in power supply units. These were expensive and not self-healing in the event of a breakdown due to high voltage surges. These condensers were usually used in 2 and 4 mfd. sizes. To obtain a large capacity, these were often built several in a single container. The container was usually larger than space in a receiver would allow, thus making a separate power unit necessary. Another disadvantage was the fact that, due to the low capacity available, large inductance values were necessary thus adding to the size and weight of the power unit.

With the commercial development of the *electrolytic condenser*, most of the above mentioned problems were solved. The electrolytic condenser is smaller in size and lighter in weight for equal capacities. It is, to a large extent, self-healing. All these facts, plus making possible the use of smaller chokes, has led to its almost universal use.

For a given area of electrodes, capacities 1000 times greater may be obtained with the electrolytic condenser than with the paper type.

As you have already studied, the electrolytic condenser and its construction, no attempt will be made at this time to explain its interior action. There are several types, however, which may be used in certain applications with better performance than other types. For instance, in Fig. 5, condenser C_1 is directly across the output of the rectifier. This type of filter circuit is termed a *condenser input filter.* If there were a large A. C. component from the rectifier, such as would be obtained from a mercury vapor rectifier tube, this large ripple would be placed directly across the condenser C_1. Due to this fact, and to the fact that a thin film is the dielectric in an electrolytic condenser, the large ripple would break-down the film. This is because the electrolytic condenser is *polarized.* A reverse voltage or a large A. C. voltage will *heat* and eventually destroy this film. If a *dry* type electrolytic condenser

were used in this position (C_1 of Fig. 5), the heat would, in addition to breaking down the film, tend to dry out the small amount of electrolyte included in the condenser. Thus, while the condenser might heal itself or reform the film, it would soon loose capacity. For these reasons, it is best to use a *wet* electrolytic condenser in an input position *where a large ripple is present.*

For the same reasons, the location of a dry type electrolytic is important. Too often these are installed close to a source of heat, such as a rectifier tube or a resistor. This is especially true in the small A.C.—D.C. type of receiver.

Some modern electrolytic condensers are mounted in a socket, similar to a tube. This method of mounting insures that the condenser will be placed in the correct position as determined by the designer. Other types mount by their leads, and it is this latter type which is so often mounted incorrectly.

FILTER CIRCUITS

Figure 5 shows a basic type of filter circuit. This represents the type of circuit used in practice today. This is a *condenser input untuned filter circuit.* There are other variations of this circuit, and these will be shown later in this lesson. As a consequence of the popularity

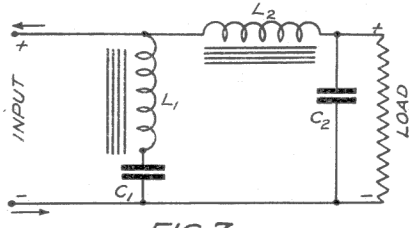


FIG. 7

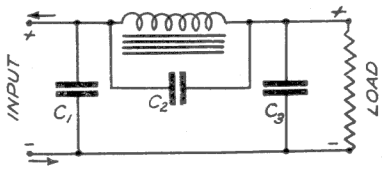


FIG. 8

of electrolytic condensers, they will be indicated in the circuits to be shown. From an engineering viewpoint, there is no reason why paper type condensers cannot be used in these same circuits if proper voltage and capacity values are observed.

Most power supply filter circuits are known as *low pass* filters. This means that they will pass only low frequencies (60-120 cycles)—these will be described later. It should be mentioned here that often *brute force* methods are employed in the design of filter circuits. This consists of using the largest chokes available along with the largest condensers. This method is adequate in low voltage receiver power supplies where the costs are low and vary only slightly as the size of the component parts is changed. In modern high voltage power supplies, thought must be given to the size of the component parts as well as to the cost so other filter methods are more desirable.

Another type of filter circuit, as shown in Fig. 6, is known as the *choke input* filter. In this circuit, the current from the rectifier entes an inductance first. In view of the fact that one of the characteristics of an inductance is that the current through it cannot be made to change rapidly, it follows that if the inductance is *large enough* the variations in the current through it may be reduced to a

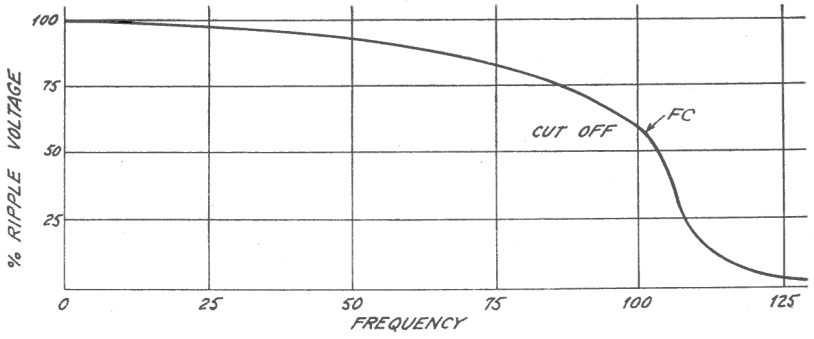


FIG. 9

large degree. This is usually insufficient so this first inductance is followed by a condenser and more series inductance.

Another type of filter circuit is shown in Fig. 7. This is known as a *high pass* filter, more correctly as an absorption type filter, and actually *shorts* out the low frequencies through the series resonant circuit L_1C_1.

In Fig. 8, a basic tuned filter circuit is shown. In this system the *tuned* circuit L_1C_2 is adjusted so as to have a high impedance to the ripple frequency. C_2 is usually .05 mfd. while C_1 and C_3 are generally 8 mfd. or larger. This tuned type circuit will be further discussed later in this lesson.

Referring to Fig. 5, it may be seen that this circuit is *not* tuned. This is termed a *low pass* filter circuit. This circuit has an increasing impedance charactertistic as the frequency is increased. This effect is shown in Fig. 9. The point FC is called the cut-off point of the filter. In designing a filter, a point FC should be chosen to have a value which is below the ripple frequency of the rectifier. For 60 cycle power supplies, FC should be *below* 60 cycles for half wave rectification and below 120 cycles for full wave rectification. The lower the FC is below these frequencies, the greater the filter efficiency.

The vertical axis of Fig. 9 is graduated in per cent of the ripple voltage. The horizontal axis is graduated in frequency. The curve illustrates the cut-off point at 100 cycles. This places it below the ripple frequency which is 120 cycles. The inductance and capacity values of the filter are so chosen as to force a near cut-off of all frequencies above 100 cycles. Thus, in Fig. 9 you will note that about 75% of all frequencies below 100 cycles will go through the filter. As there are no frequencies *below* the *predominent* frequency of 120 cycles, the curve shows that only about 5% of the ripple frequency will get through the filter. If other frequencies were present, the FC would be made lower or higher as the case demands.

Theoretically, the cut off frequency for a low pass filter means that the filter will refuse to pass all frequencies above the cut off or FC point. Thus, if FC is chosen to be 40 cycles, it simply means that the filter will allow only a small percentage of any frequency above 40 cycles to pass.

A great percentage of these *unwanted* frequencies are passed back to the positive return to the rectifier by condenser C_1. A further analysis, however of this circuit will aid in your understanding of the actions of other circuits to be described.

As you have learned, the output from a rectifier will be pulsating in nature. These pulsations, however, are made up of the top part or crest of each half cycle (with full wave rectification). This top part of each half cycle would not be represented as a series of straight lines, but as a series of small arcs or portions of curves representing the wave form of the AC supplied to the rectifier. While their average value is a high DC voltage, *superimposed on this DC is the AC ripple component.* This DC with its ripple is applied across C_1 (in Fig. 5). Although the average charge delivered to this condenser remains at several hundred volts, its charge actually *varies* as the superimposed ripple voltage varies. During a *rise* in *ripple* voltage, this condenser can absorb the additional voltage. However, during the fall of the ripple voltage, this condenser must discharge and since it cannot discharge through the rectifier, it must discharge through the load and back through L_1 to the rectifier.

While this ripple voltage is charging C_1, it is also starting to flow through L_1 from the load. Because of the *inductance* of L_1, this rise or change in voltage is opposed for an instant. Providing that the values of C_1 and L_1 are chosen correctly, at the time this increase of ripple voltage has started through L_1, the ripple voltage starts to fall. Having a charge equal to the ripple peak, the condenser C_1 now discharges *through* the load. Thus the *combined* actions of C_1 and L_1 combine to hold the current to an average level value. C_1 acts as a reservoir, alternately storing energy and then filling in the valleys of the peaks. This combined action can be compared to that in a water line supplied from a single action pump with a storage tank connected to the water line between the pump and the outlet of the line. Here, the *resistance* to the flow of water offered by the pipe (or line) is comparable to the inductance while the tank can be likened to the condenser, alternately storing water from the pump, yet maintaining a steady pressure on the line.

Returning to Fig. 9, it may be seen that if the cut off point or FC is chosen at 40 cycles, and if the ripple frequency is 60 cycles, then a practically hum-free DC should be available for the tubes of the receiver.

The formulas for determining the values of inductance (L) and capacity (C) for an untuned filter follows, where C = microfarads, L = henries, FC = the cut off frequency, and R = the load resistance. Thus,

$$C = \frac{318{,}300}{FC\ R}\ ,\ L = \frac{3{,}183\ R.}{FC}$$

The load resistance mentioned in these formulas includes not only the resistance of the voltage divider, to be explained later, but also the DC resistance load effect of all the currents drawn by the

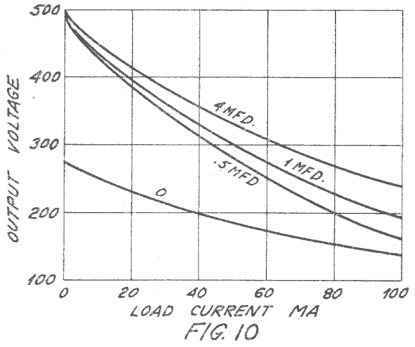


FIG. 10

tubes the power unit is to supply, plus the load of a voltage regulator, if one is used. Voltage regulator methods will also be described later in this lesson.

In designing a filter such as the one in Fig. 5, the resistance load is first calculated. Next, L and C are calculated. A value of C is then chosen, which will allow the use of a standard condenser, and the value of L recalculated, so as to provide the correct LC product.

For example, suppose the original L and C calculation showed that L=20 henries and C=7 mfd. The product of these is equal to $7 \times 20 = 140$. Since 7 mfd. is an odd capacity value, a standard value of 8 mfd. is chosen instead. Then, to find the new value for L, divide the LC product by the new C value, which, in this case, is 8. Then $\frac{140}{8}$ = 17.5 henries. Thus, the iron core choke coil should have an inductance of 17.5 henries. The same principle would be applied for other L and C values.

In the case of condenser input filters, the input condenser, for instance C1 of Fig. 5, has a great deal to do with the output voltage of the filter. This is because the condenser charges to the *maximum* peak *voltage* of the rectifier output. This is in contrast to the action of a *choke input filter*. The effect of the value of an *input condenser* is shown in Fig. 10. Since this condenser always raises the voltage by its addition to a filter circuit; generally speaking, the greater the value of this input condenser, the higher the output voltage. This raising of voltage will, of course, be limited to the maximum DC output of the rectifier, including the peaks of the ripple. Furthermore, though this condenser does raise the voltage, the *degree* to which it does is limited by the amount of current drawn by the equipment the power unit supplies. You will note in Fig. 6 that *as the current is increased, the output voltage decreases.* The important fact to realize is that C1 not only serves to removed the ripple but to raise the output voltage as well. This action also aids in voltage regulation as will be explained later.

The effect of the input condenser on ripple voltage is shown in Fig. 11. It may be seen that above 8 mfd., increasing the capacity has very little effect on the percentage

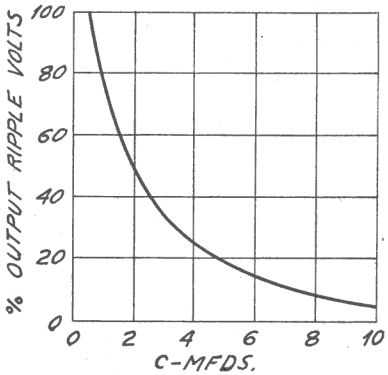


FIG. 11

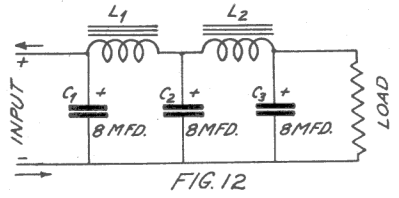


FIG. 12

of ripple voltage. In this (Fig. 6) capacity input filter, about 10% of the ripple would get through the condenser C1 and choke L1. The condenser C2 in conjunction with the load resistance *must* form the rest of the filter action. This system is a basic filter system and termed an untuned capacity input filter circuit. It is also cometimes called a *brute force filter*. Such a filter is commonly used in small receivers where the *audio* amplification is low and where the power demand is low.

In Fig. 12, a two section untuned capacity input filter circuit is shown. This is a much better filter than the circuit described before and illustrated in Fig. 5. A comparison of the two circuits will show that Fig. 12 is composed of two of the circuits illustrated in Fig. 5. However, if, in Fig. 12, C1 and L1 remove all except 10% of the ripple, it follows that the ripple must be further reduced by C2 L2, and C3. In analyzing the circuit, it may readily be seen that if a 100% ripple were fed the input of the filter and if C1-L1 removed 90%, leaving 10%, then C2L2 will remove 90% of this remaining 10%, this being equal to $\frac{10}{90} = 1\%$. Thus, only 1% of the ripple gets into the output at the load. In practice and in the average receiver, from 1 to 2% of the ripple at the input is present in the output.

Condenser C3 at the output of the filter in Fig. 12 acts as a reservoir of power in addition to aiding in removing ripple. It tends to keep the voltage at the output of the filter at a steady value.

Due to large signals or high volume levels in a receiver, the power unit supplying it will be subjected to large variations in current. This is especially true in class B and C amplifiers. The combination of the voltage divider (and its filter or by pass condensers) and the output or final condenser of a filter act as a storage tank of energy to handle these current surges.

It may be stated simply that a *condenser* in a filter circuit aids in maintaining a *constant voltage*, while a filter choke aids in maintaining a *constant current*. This is due to the following—you will remember that chokes L1 and L2 of Fig. 12 act to prevent a change in current flow. This would interfere with the varying current required by the tubes of the receiver if it were not for the final condenser C3. As this condenser is continuously charged by the output of the filter, when an additional quantity of current is demanded, C3 discharges. Because the tubes of the receiver are at a lower potential than the output of the filter, C3 can only discharge towards the load. C3 immediately charges again to a value equal to the output of the filter and is ready to again supply an extra current. Thus, C3 *aids in regulation.*

You should realize that many factors of design influence regulation. In modern receivers, this is

extremely important. In ultra high frequency equipment for instance with a local oscillator in a receiver used to *hetrodyne* a signal down to a few megacycles, a change in plate voltage *of* 1 *volt* will change the frequency of the oscillator over 5 *KC*. Many modern receivers have special devices included in the power unit called *voltage regulators*. These will be described later. The design features mentioned in the foregoing are becoming increasingly important as higher frequencies (shorter wave lengths) become more popular.

Although the chokes illustrated in most filter circuits are in the + or positive lead from the rectifier, there is no absolute rule for this. For instance, a comparison between Fig. 12 and Fig. 13 will show that the circuits and actions are the same. The main difference being that in Fig. 12, ground would be connected at the minus or negative end of the load, or at a point close to this negative end. The reason ground might be connected at a point *near* the negative end of the load would be to supply a *negative bias* for *power amplifier* tubes, as will be explained under *voltage dividers*. In Fig. 13, ground is connected between the two chokes *and for the same reason*. The voltage drop across the second choke in Fig. 13 would supply the bias voltage in this case as will be brought out later.

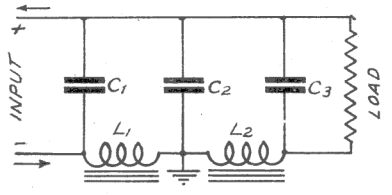


FIG. 13

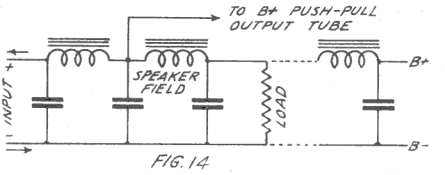


FIG. 14

The circuit of Fig. 13 is used in many receivers. Quite often it is desired to furnish the field of a dynamic speaker, yet not depend on the speaker field for all the inductance needed in the filter. In these cases, a choke would be used at L1 and the speaker field at L2. Due to the removal of part of the ripple by C1-L1 and C2, there will not be present, in the speaker field, as large an amount of ripple as there would be in other circuits. Here again, either choke or speaker field could be in the positive or negative lead of the filter circuit. One could be placed in each side of the filter circuit. All of these arrangements would give about the same results.

Another variation of this same *two stage* filter circuit is shown in Fig. 14. Here, the plate voltage for the push pull output tubes of the receiver or amplifier is taken from the point indicated. While a greater percentage of hum may be present at this point, this is largely nullified by the effect of cancellation in a push pull output stage. This is due to the voltage being fed to the center tap of the output transformer. You may see that less filtering is necessary for the output stage, as there are no previous stages to amplify the ripple or hum.

As shown by the dotted lines in Fig. 14, when a minimum of hum

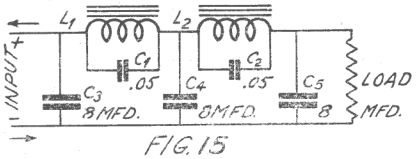


FIG. 15

is to be tolerated, an additional filter section may be connected to the output of the main filter. This additional filter section may consist of an additional choke and capacity or, as in most cases, it consists of a simple RC or *resistance-capacity* filter. This situation exists in many modern *FM-AM*-and *Television* receivers, where the response is so flat that a very small ripple percentage would result in very evident distortion or an annoying hum.

TUNED OR RESONANT FILTERS

An improved two section filter is illustrated in Fig. 15. This circuit operates exactly as the other filters described, but with the following improvements. By the addition of the small condensers C1 and C2, each section of the filter is *tuned to resonance* with the ripple frequency. The two resonant circuits L1-C1 and L2-C2 offer a very high impedance to the ripple frequency. Because of this high impedance, at the ripple frequency, there is a maximum voltage drop at the ripple frequency across the chokes and condensers in parallel with the consequence that a large percentage of ripple cannot go through the load.

In many cases, this results in a *reduction* of the size and weight of the chokes used. While this type of filter requires very careful design, it is often used in modern communication systems. As may readily be realized, it *must* be used on the frequency for which the power unit is designed.

This type of filter must be applied to constant loads, for, as the current through the chokes varies, their impedance will vary. Due to this fault, a filter of this type, if used on a varying load, would go into and out of resonance. Under these conditions, a varying amount of hum would result, which would be objectionable.

ABSORPTION TYPE FILTERS

The filter circuit shown in Fig. 16 is sometimes called a *high pass* filter because it allows only the frequencies above the cut off point to pass. It is also known as the absorption filter. As may be seen, the choke L1 and condenser C1 are in series across the output of the rectifier. Note, however, that this is a series resonant circuit and if the values are properly chosen, it will short circuit the ripple frequency. The condenser C2, in this case, would be large—12 or 16 mfd. As this is only suitable for very small receivers, the choke L1 is usually the speaker field. As the ripple voltage is insufficient and unsuitable to operate the field, a resistance R is connected across the condenser C1 to provide a path for the DC necessary to operate the field. The value of R is much higher than the capacitive react-

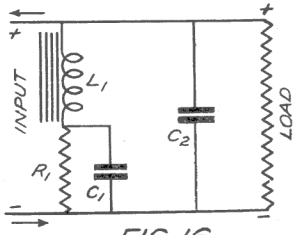


FIG. 16

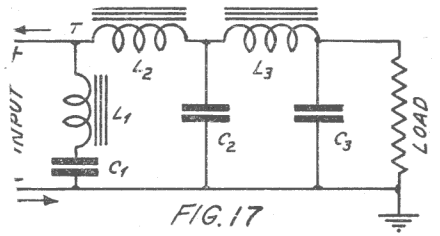


FIG. 17

ance of the condenser C1 at the ripple frequency. The resistor broadens the peak of impedance of the circuit and offsets any slight variation in the capacity of C1.

COMBINATION FILTER CIRCUITS

A much better type of filter is illustrated in Fig. 17. Note that this is a combination of Fig. 12 and Fig. 16. In this circuit, the high pass filter cut-off point must be above the ripple frequency, and the cut-off point of the low pass filter must be below the ripple frequency. This combination is the best type of circuit, although it is the more expensive. In radio, this circuit is called the Clough filter.

A more economical version of this circuit is shown in Fig. 18. This was developed by Meisner and is so designated. L1 and L2 are wound on the same core with their common connection or tap brought out at T. In other words, this circuit makes use of a tapped choke.

Across the input condenser C is connected. The return to the rectifier is from tap T. The values of L1-C1 and L2-C2 are so chosen that the magnetic fields produced by the two coils are equal. As the current of L2 rises in the direction shown by the arrow at the same time current also rises in L1 caused by charging C1, and, since current flows in the two circuits in opposite directions away from point T, their magnetic fields cancel one another. In this way, the ripple voltage is greatly reduced. The reason for combination filter circuits like Figs. 17 and 18 is because of the economy of parts—it being much cheaper to build this type of filter than some others. Much lower values of parts may be employed, thus, the economy.

In circuits of the type shown in Fig. 6, the output of the rectifier is fed to a choke first. Then follows a low pass filter, as has been described. Here, however, is a different condition at the input. The simple action of a choke input filter has been stated. Often this circuit is used with what is known as a swinging choke. This type of filter circuit is used most often with mercury vapor rectifiers for high voltage current applications. Aside from the *improvement* in *regulation*, the use of a swinging choke will not deliver the high voltage that a *capacity* input filter permits. In radio circuits where the maximum load current drawn from the rectifier is subject to *wide variations*, the first choke coil must function with

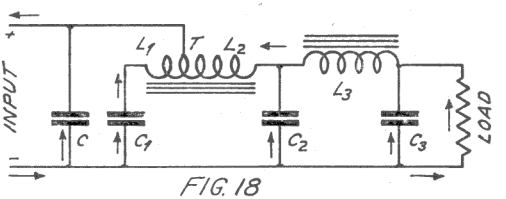


FIG. 18

widely differing load currents. When using mercury vapor rectifiers, due to their small internal voltage drop, current flows for a longer period of the cycle than with other types of rectifiers. If a choke input filter is used, the surge or rush of current when the power is first turned on, will be retarded. If a capacity input filter is used, the initial rush of current could damage the rectifier tube.

A swinging choke is usually made with little or no air gap, thus with little or no current flowing, its inductance is high. This is necessary because the function of an input choke is twofold—first, to raise the *ratio* of *average* to *peak* current and second, to prevent the output voltage from rising above the average AC voltage applied to the rectifier. Both of these functions require a high inductance. Swinging chokes operate on the theory that by their use current never stops flowing through the rectifier between half cycles. The flow of current is prevented from falling to zero by the energy stored in the choke (its magnetic field). This is similar to the energy stored by an input condenser, the difference being that while the condenser aids in maintaining an average *voltage*, the input choke aids in maintaining an average *current*. Thus, it is more suitable for high power demands.

Research has determined a certain *critical* inductance value for an input choke. This may be stated by the formula $L = \frac{\text{Load Resistance.}}{1000}$ (For 60 or 120 cycle ripple).

When values equal to those obtained by this formula are used, a large saving in cost and sizes of other components of the filter may be realized.

The *swinging choke* is so termed because while only a light load is being drawn from the filter, the *critical inductance* should be highest. When the maximum load current is drawn, the critical value is lower. Since the value of inductance will be *reduced* as the current *increases*, the choke characteristics will change or swing as the load varies. Thus, if the minimum load is 20,000 ohms of reactance and the full load is 5,000 ohms of reactance, a choke which *swings* from 20 henries to 5 henries will be satisfactory.

Due to the limited space in the popular midget receivers, and to the small load, it is possible and necessary to use simple and inexpensive filters. A circuit similar to that shown in Fig. 19 is used in these cases. Here, only the speaker field is used as a choke. Condensers C1 and C2 usually are 12 or 16 mfd. each. This is necessary to make up for the lack of another choke. From what you have learned you may see that this circuit is useful *only* for *light current* load applications.

As the speaker field's *resistance* produces an average drop of 100 volts, some designers make use of this voltage drop, as illustrated in

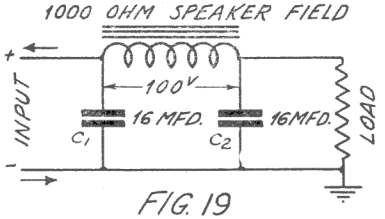


FIG. 19

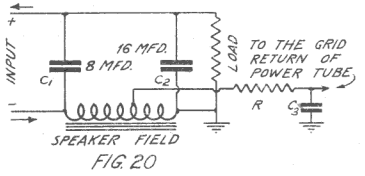


FIG. 20

Fig. 20. In this case, the speaker field is in the *negative* lead and is *tapped.* Thus, if the tap is placed at the *proper* point, the correct *negative* bias for one or more tubes may be obtained in an economical manner. Since this negative bias is to be applied to the *grid* circuits of tubes, additional filtering may be necessary. This may be effected by connecting the resistor R and condenser C3 in the tapped lead from the choke.

In cases where the field is *not* tapped and the above conditions for bias are needed, an arrangement such as that shown in Fig. 21 can be used. In this circuit (Fig. 21), two resistors R1 and R2 are connected in series *across* the choke or speaker field. These resistors *must* be *proportioned* correctly to obtain the right bias voltage. The total value of the series must be high in relation to the reactance of the choke. It has been found that a total resistance 10 or 20 times the reactance of the choke (as expressed in ohms) should be used. For example, suppose a 100 volt drop existed across a choke, the reactance of which is 10,000

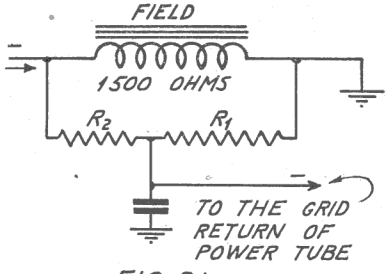


FIG. 21

ohms at 120 cycles. If the series resistance is made 10 times the reactance, the total should then equal 100,000 ohms. Suppose, also, that a bias of 40 volts were required. The first step in solving this problem would be to find the current flow through the resistance. In this case, it will be equal to

$$\frac{100}{100{,}000}=.001$$

ampere or 1 milliampere. As a 40 volt drop is required across R1 (of Fig. 21), then $R_1=\frac{40}{.001}$ or 40,000 ohms. As a total resistance of 100,000 ohms is required across the choke R2 would equal 100,000 — 40,000 or 60,000 ohms. This same principle would be applied to other similar circuits. One more calculation is necessary for practical work, however. Economy would call for the use of the smallest resistors, while good practice would require the use of resistors able to handle, or disspiate the heat from, the *power* required. The rating in watts for these resistors is equal to EI or I^2R. In this case, the wattage is low (0.1 watt), so ½ watt resistors could be used safely. The capacity in watts of resistors used in radio must be considered in each application to assure continuous *safe* operation.

Another variation of connecting resistances in the negative lead of a filter to provide several values of bias voltages is shown in Fig. 22. The resistances in this case are in series with the choke in the negative lead of the filter. A *different condition* exists because *all the power used by the load* must flow

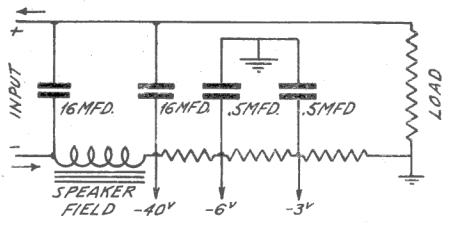


FIG. 22

through these resistors. In this situation, the total *resistance* in the negative lead should be *less* than the reactance of the speaker field or choke.

Often, the series method of connecting resistors is employed when the speaker field or choke is in the positive side of the circuit.

The fundamental principles and theory of all power unit filter circuits are alike. As you work with equipment, you will often find variations in condensers, chokes and resistors, and there will be many variations of the circuits described in this lesson.

VOLTAGE DIVIDERS

If a filter circuit were not loaded, the voltage across the condensers would rise to a value which could damage them and the rectifier. Because the rectifier is a *one-way* or unidirectional device, transient voltages, line surges and even oscillation can aid in building up *dangerous voltages* in an *unloaded* filter. For this reason, a *bleeder* resistance is always placed across the output of a filter in power supply units unless the load is arranged to perform this service. That this may serve another purpose will be shown.

If only *one* tube was to be supplied with power, or if only *one* voltage is necessary, a power system designed to furnish that particular voltage across the *bleeder* resistance could be designed. Where numerous different voltages must be supplied, as in modern receivers, a separate source of power for each particular voltage would be too expensive. The function of supplying different voltages from power units, as well as acting as a bleeder resistance for the filter, is usually performed by what is known as a voltage divider. A voltage divider is nothing more than a *network* of resistor units. These may be connected in series or parallel, or a combination series parallel circuit may be used. The resistors involved may be in the form of one or more units. Often, these voltage divider resistors are placed at several points in a chassis, so that they become part of the wiring.

A voltage divider is usually very simple when drawn separately. Often, however, wiring diagrams are so arranged that it is difficult to see the network clearly.

Regardless of the receiver requirements, there are two methods of obtaining a number of different voltages from a single source. These are the shunt and series divider systems.

For this study, it is important that you consider the supply voltage to any tube or stage, as the voltage impressed at the B+ end of the tube load and *not* at the plate of the tube.

A voltage divider is illustrated in Fig. 23. Four different voltages are shown with respect to ground. This is the *shunt* method. The total resistance is *shunted* across the output of the filter. Taps on the resistor furnish the

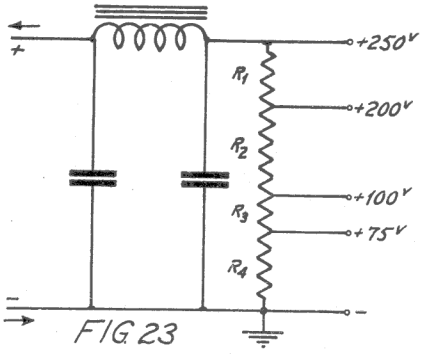


FIG 23

different voltages. As long as the current furnished at each tap remains constant, the voltages at each tap will remain constant (with constant supply voltage). If, for instance, the tube supplied by the 100 volt tap were to burn out, both resistors R1 and R2 would be carrying less current and the 250 and 200 volt taps would *increase* in voltage. Slightly more current would be forced through R3 and R4 and by this increase in voltage the 75 volt tap would increase slightly. It may be seen that the correct voltage depends on each tap supplying the correct current.

The total resistance across the output depends on the type of filter used. With a choke input filter, the constant current flowing through the bleeder or voltage divider is often up to 20% of the total current output of the rectifier and filter. With a capacity input filter, this constant or bleeder current through the resistor is usually limited to 10%. Either of these percentages may be altered by the type of *voltage regulator,* if such is included in the circuit. You will see how this may affect the design when voltage regulators are studied in this lesson.

The current flowing through R4 in Fig. 23 represents the bleeder current percentage and is wasted.

The value of R4 in Fig. 23 may be calculated (for a capacity input filter), assuming a 10% loss. If the power unit is to furnish 80 ma., only 8 ma. should be allowed to flow through R4. As there is to be a 75 volt drop across it, then it should have a value of $\frac{75}{.008}$ or 9,375 ohms. If the 75 volt tap is to furnish 2 ma., this will make a total of 10 ma. through R3. With a 25 volt drop across R3, then R3= $\frac{25}{.01}$ or 2500 ohms. In this way, all of the resistors for a voltage divider may be calculated. As you have already studied resistance caluculations in your previous S. A. R. lessons, you will be able to figure these values easily. (See lesson ND-6).

An example of the series system is shown in Fig. 24. This system is sometimes used in AC-DC receivers. There is no complete circuit from negative to positive of the power supply. The various tubes and circuits are supplied through limiting resistors directly, which supply the necessary voltage drop, so that the tubes will be properly supplied.

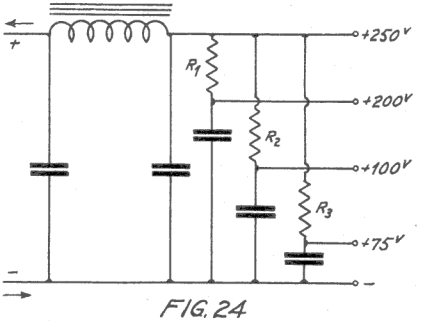


FIG. 24

For example, if the 200 volt terminal must supply a total of 6 ma., resistor R1 must drop 50 volts (250−200), its value must be $\frac{50}{.006}$ or 8333 ohms. In the same way, assuming that the 100 volt terminal must carry 15 ma. and must drop 250 − 100 =150 volts, the result is $\frac{150}{.015}$ =10,000 ohms. With this system, there is no bleeder current that is wasted. All the current must flow through a tube or its circuit. This system is also used in certain battery operated circuits where a direct waste would quickly run down the B batteries.

As has been mentioned before, when more current is drawn from the power unit, there will be an increased voltage drop across the rectifier and the transformer supplying it. When this happens, the entire power supply will regulate its voltage distribution. All of the voltages will suffer reduction, and the process of the power supply making adjustment for the new condition of load is called *regulation.* The combined efforts of the transformer, the rectifier, the filter system, and the voltage divider system all contribute to the total regulation of the power unit. When the combination of all these units produce a minimum reduction in output voltage with a given increase in current the power supply is said to have good regulation.

A combination shunt and series voltage distribution network is shown in Fig. 25. Two requirements of a receiver are supplied directly through resistors R1 and

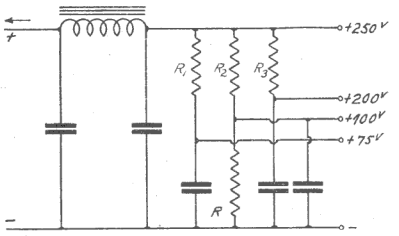


FIG. 25

R3. The screen voltage is supplied through the shunt circuit, comprising R and R2. These two resistors (R and R2) are also the bleeder for the filter.

Knowing these *basic* filter and voltage distribution systems, you can explain every type of voltage source used in modern electronic equipment. There is one phase of voltage divider networks which must be permanently and thoroughly understood, however. This is the *ground* or *chassis connection* of a voltage distribution system.

From the start, you will benefit if you always regard a given voltage *as being relative* to the ground or the chassis of any equipment in question. Ground *does not* mean the most negative or most positive polarity. On the contrary, ground usually is connected to a point on the voltage divider network which will make available not only the positive or + values needed for vacuum tube operation, but the negative (—) or *bias* voltages as well. Aside from the convenience of having one source of both *plate* and grid, or bias, voltages, there is another good reason for using this common source. If the bias voltages were obtained from another source; for example, from a C battery, then if the power supply *line* voltage were to vary and thus

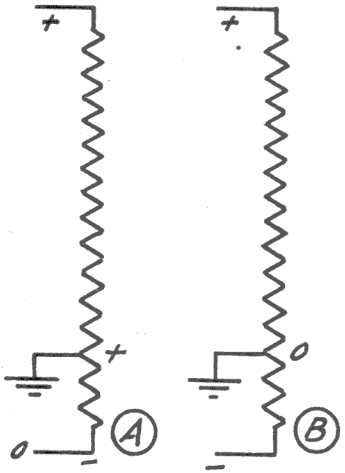


FIG. 26

change the plate voltage applied to the tubes, the bias voltages would remain fixed. This would affect the operation of the tubes supply because it changes the ratio of grid bias to plate voltage. Where both voltages are supplied from the *power* unit, any line variation will affect both proportionately, thus stabilizing the operation of the tubes and circuits.

An example sometimes found of different *polarity markings* for two identical voltage divider schematics is given in Fig. 26. In both cases, the lower end of the resistors is the *most negative.* The ground in *both* cases is *positive* in respect to the lower end of the resistors, however, in one case, the ground is marked + and in the other it is indicated as minus or negative. Where ground is marked positive +, the lower end of the resistor is marked zero; where it is marked zero, the lower end is marked negative.

It is *invariably* better to regard ground as zero and consider *all other voltages* as being either *positive* or *negative* with respect to ground.

It must be remembered that while the circuits, thus far described, are the fundamental circuits, they may not always appear as they are shown in this lesson. As mentioned before, the entire voltage distributing network may be broken up and shown at convenient points in a diagram. They may actually be so diversified that they may not be immediately identified as part of the voltage distributing network.

In the latter part of this lesson several popular, modern, complete receiver circuits will be analyzed. All of the parts making up the power supply, including transformers, rectifiers, filter systems, voltage regulator systems and voltage distribution networks will be pointed out.

VOLTAGE REGULATOR SYSTEMS

The requirements of today's modern receivers is such as to demand, in certain cases, very stable voltage. High frequency, FM (frequency modulation) and television receivers and their associated power units aften embody the use of *voltage regulator tubes.* All of these systems make use of *special tubes* designed for the purpose, and all may be termed *electronic voltage regulators.* Two types of tubes are used at present. One system makes use of *cold cathode gaseous* regulator tubes, such as the VR series, the VR 90-30 and VR150-30, etc. The other uses thermionic tubes such as 6F5, 6K5 and power tubes such as the 2A3, etc.

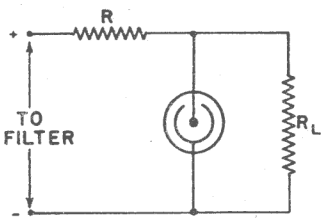


FIG. 27

The gaseous VR (voltage regulator) system will first be described.

At this point your attention is directed to this fact—unless a complete power supply schematic diagram is shown in the circuits illustrated, the *input* will be assumed to come from a filtered source of DC, and the *output* will be considered as fed to a voltage divider or to the *particular stage* for which the voltage is to be stabilized. This allows the use of simple straightforward diagrams, making it easier for you to understand the actions involved.

A basic VR circuit is illustrated in schematic form in Fig. 27. Note that a limiting resistor is *always* placed between a VR tube and the source. If this were omitted and the load were removed, a high current could flow which would damage the VR tube. This protective resistor is called a current limiting resistor. Its value may be calculated by the formula:

$$R = \frac{E_{IN} - E_{VR}}{I}$$

In this case

R=Resistance of limiting resistor.

E_{IN}=Voltage of supply.

E_{VR}=Voltage drop across the tube (or tubes).

I=Safe maximum current capacity of VR tube.

In the numbering system employed to designate VR tubes, the first number indicates the *operating* voltage and the second states the *maximum* current in milliamperes that can be passed *through the tube* and still maintain the required *voltage drop*. The VR-150-30, for instance, is to be used with a *supply* potential of 150 *volts*, and at this voltage the *current through the tube* must be limited to *not over* 30 milliamperes. The *starting* or initial *ionizing* voltage, as given by the manufacturers, is 180 volts; for stable operation a minimum current of 10 ma. is necessary.

A VR tube arranged as in Fig. 27 has the property of maintaining the voltage *across its terminals* at a fixed value. The load is placed in parallel with the tube, and the voltages required may be supplied by taps from this load resistor or other similar divider networks. The variations in voltage are absorbed in the limiting resistance. If the current through the tube is limited to 10 ma. then a maximum variation in current to the load may be 20-25 ma. without exceeding the safe current through the tube of 30 ma. The voltage at the load resistance will not vary more than approximately 1% with the use of such a tube. If high values of regulated voltage are required, two or more VR tubes may be connected in *series*. This is shown in Fig. 28. The maximum current is *still* limited to 20-25 ma., however, and, as this is not within the current values usually desired and as the *voltage* ranges are so limited, other types of voltage regulation have been found *more* satisfactory.

The characteristics curves of the

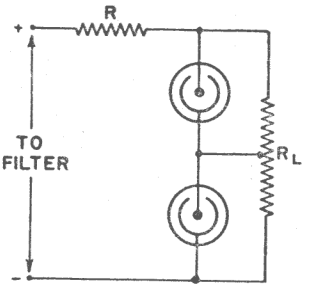
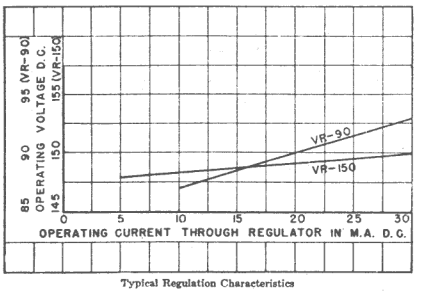


FIG.28

VR-90 and VR-150 tubes are shown in Fig. 29.

Automatic voltage regulation can be provided by placing in series with the load a resistance whose value can be automatically regulated as the load current or *output voltage* varies. The most practical manner of accomplishing this is to place a triode in series with the rectifier output. By arranging a suitable network, the bias of the triode grid can be made to vary as the output voltage varies. This will change the internal resistance of the triode and can be made to automatically adjust the cathode to plate resistance in such a way that the output voltage will be held to within 0.1% or better of the required constant voltage. The use of a triode in this manner will *greatly aid in filtering.*

The method of using thermionic voltage regulators is shown in Fig.



Typical Regulation Characteristics

FIG. 29

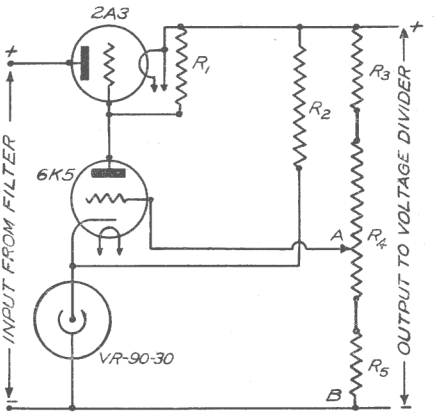


FIG. 30

30. As may be seen the 2A3 is used as the *variable series resistance.* The bias on this tube is the voltage drop across R_1. This drop is determined by the current passing through the 6K5 which is governed by its bias voltage. This bias voltage is the sum of the voltage drop from A to B. Since the voltage across the VR tube is constant, a change in the voltage from A to B will affect the grid of the 6K5. This small change will be amplified by the 6K5, and thus it will produce a larger change in the characteristics of the 2A3. To insure proper operation, the 2A3 tube should be operated on the *linear* portion of its curve. The adjustment at A of R_4 allows the selection of the correct amount of bias applied to the 6K5 and is used to adjust the percentage of correction for a given change in output voltage.

Variations in this circuit may be found using more tubes to multiply a change in voltage. The theory you have previously studied of amplification can be applied in these cases. In some cases, a small *neon* or glow discharge lamp may

take the place of the VR tube in Fig. 30. All voltage regulator systems are designed around these basic circuits.

COMPLETE RECEIVER CIRCUITS

A voltage divider is a very vital part of any radio set. In general, it is nothing more than a resistor network so arranged as to distribute the voltage available at the output of a power unit. This power unit may be of the A. C. or D.C. type. Also, a voltage divider may be used to distribute the output of a battery or batteries used to operate a radio receiver. Whatever the source of power, it is considered to have two terminals which feed the *load* and this, in turn, consists of the tubes as well as the voltage divider. The two terminals of the usual power unit are, in the case of full wave rectifiers, the cathode of the tube which is considered positive and the center tap on the high voltage secondary which is considered negative. In the case of half wave rectifiers, the cathode of the tube is positive and one side of the A. C. line is considered negative. In D. C. power units the polarity of the power line establishes the positive and negative terminals of the power unit for in this and in battery operated circuits, the correct polarity must be observed else the radio set will not work. This means that the positive side of the D. C. power line must connect to the positive of the D. C. power unit with like negative connections being observed. Also, in battery operated circuits, the positive and negative of the battery or batteries must connect to corresponding positive and negative points in the receiver circuit.

Thus, in any voltage divider problem a cardinal principle is to *first establish positive and negattive points which feed a given circuit.* This is necessary in order to have a starting or reference point. In radio service and repair work, you will be constantly dealing with polarity of circuits, and you must learn how to establish the polarity quickly. Thus, always pick out the *most positive* point in a circuit as well as the *most negative.* All other intermediate points in the circuit will then be either less positive than, for instance, is the cathode of the rectifier or less negative than, for instance, is the center tap to the high voltage winding of the power transformer. This brings up the basic fact that an intermediate point along a given circuit can be both negative and positive but not to the same reference point. The circuit of Fig. 31 will make this clear. This shows an ordinary pentode tube connected across a voltage divider which, in turn, may be considered to be fed by a rectifier tube and proper filter. There are three resistors in the voltage divider with

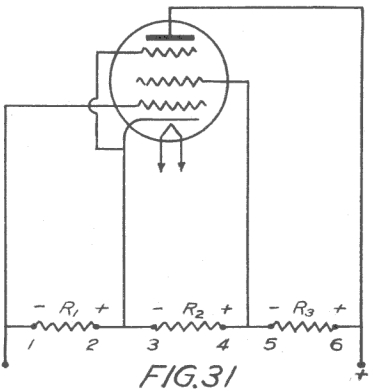


FIG. 31

their normal polarity indicated. In this network, R_1 is the most negative in the group. R_3 is, of course, the most positive. This is considering the resistors as single units with respect to any other part of the circuit. Now what about resistor R_2? Is it negative or positive? It is, in fact, both negative and positive. It is negative in relation to R_3, but it is positive in relation to R_1. This is true because it is less positive than R_3 but more positive than R_1. This is a basic circuit principle, and you ought to thoroughly understand it.

Each of the resistors in Fig. 31 has two terminals and because of current flow through them, it is another basic fact that a voltage drop occurs across each resistor equal to I x R. Because this voltage exists, one end of each resistor will be positive and one end of each will be negative. With these basic facts in mind, certain polarities may be established for Fig. 31, and the same principles will apply to all voltage dividers. First consider R_1. Number 1 of it is negative to all other parts of the circuit. Number 2 of R_1 is positive in relation to 1 of R_1 but negative in relation to 4 of R_2. This means 2 of R_1 and 3 of R_2 have the same polarity. Number 4 of R_2 is positive in relation of 3 of R_2 as well as 2 and 1 of R_1. However, it is negative in relation to 6 of R_3. This establishes that 4 of R_2 and 5 of R_3 are at the same polarity. Thus, these two points are positive in relation to R_2 and R_1 but negative in relation to 6 of R_3. Number 6, of course, is positive in relation to all other points in the circuit.

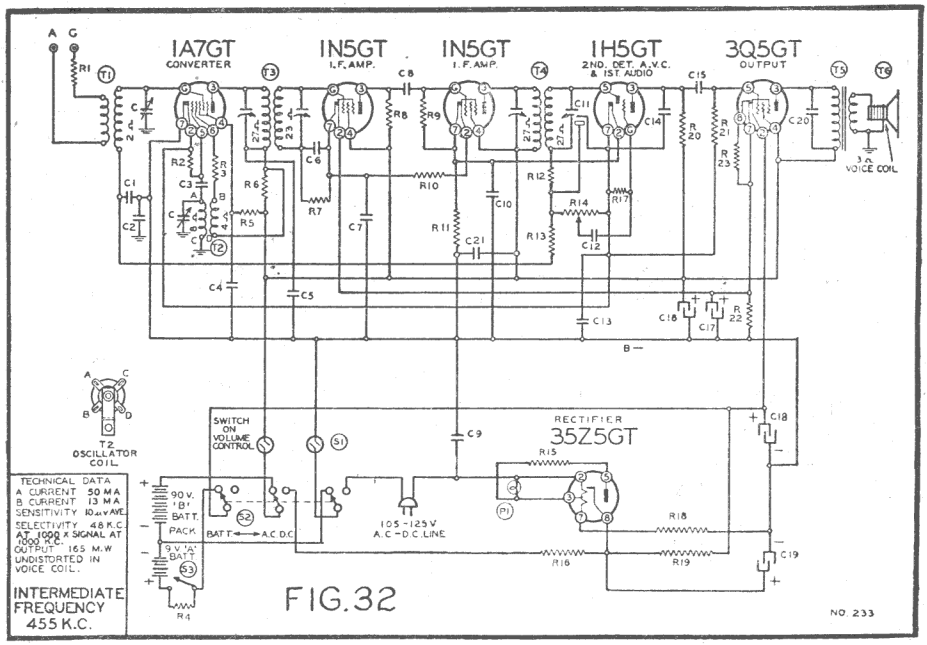
From these basic principles you should understand *that polarity is always relative* and when one point in a circuit is established as either positive or negative, it must always be in relation to some other definite point in the circuit.

Here are three basic rules which apply to all voltage divider problems. First, establish the most negative and positive points. All other points in the circuit can then be made either positive or negative in relation to these two points. Second, every resistor *through which current flows* will automatically have one end positive and one end negative. Because of this fact, a *voltage drop* occurs across the resistor. It is the purpose of a resistor to reduce voltage from a higher to a lower value. Third, if the resistor, for example, reduces voltage from 100 to 75 volts, it is clear that 25 volts *is lost across the resistor*, and this is the amount of the *voltage drop*. This same general principle is true for all resistors.

All the basic formulas for voltage divider design and replacement have been given in your lesson ND-6. So if you have forgotten these basic formulas, be sure to refer to ND-6 for the details.

With the foregoing explanation in mind you are ready to take up the study of complete receiver voltage distribution networks. Two types of circuits will be discussed, and remember the purpose of it is to show how various tube circuits may be fed from one voltage source. All other radio sets work on the same general principles.

The first circuit to be considered is shown in Fig. 32. It is designed to operate from 105-125 volts A. C.



or D. C. It may also be operated from batteries as indicated by the circuit. An analysis of the voltage distribution system can be most easily made by assuming the receiver to be supplied from a *D. C. power line.* The values of voltage in the circuit will be slightly higher when operated from an A. C. power line. The half wave rectifier is used for *both* A. C. and D. C. power line operation, but is *out* of the circuit when battery power is used. This is brought about by proper use of switch S2. Because it is difficult, from a schematic diagram as in Fig. 32, to visualize the D.C. distribution from the rectifier (35Z5) your attention is directed to Fig. 33. Here the distribution circuits and elements of Fig. 32 are shown in a simplified manner. The numbering and lettering of the circuit elements are the same in both Fig. 32 and 33. *Tube filaments and heaters are illustrated as resistances, and the socket or pin numbers are shown. Dashed lines indicate grid returns or bias supply connections.*

Power enters this circuit (Fig. 33) at the two terminals as indicated at the left of the diagram. Note that the *heater* of the 35Z5 *is in series with R*18. This series circuit is directly connected across the power line. Notice, also, that the pilot lamp is connected across terminals 2 and 3 of the filament (symbolized as a resistance) of the 35Z5. The manufacturers of the tube have proportioned the *resistance* of the filament to allow the use of a pilot lamp of 7 volts at 150 milliamperes. Simple caluculations involving the use of Ohm's law will show why the resistance of R18 is needed. A 35Z5 tube filament draws .15 ampere at 35 volts.

Referring to the formula $R = \frac{E}{I}$

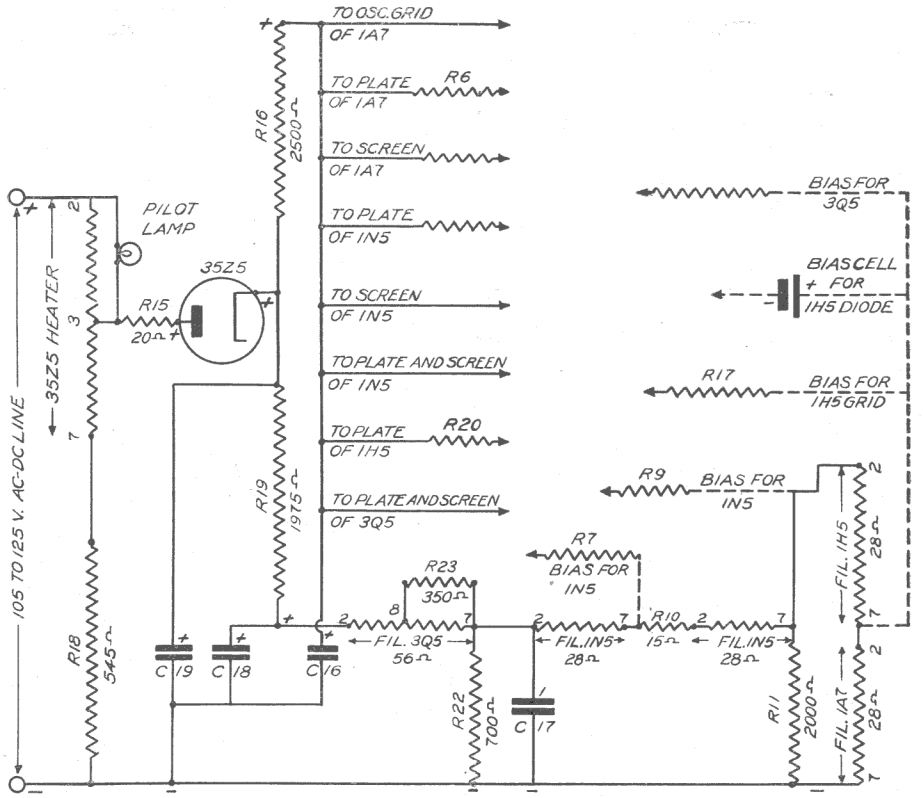


FIG. 33

then $R=\frac{35}{.15}=233.3+$ ohms. As the receiver is intended to operate from 105 to 125 volts, an average line voltage of 117 volts may be assumed for these calculations. Using the same formula, a voltage of 117 volts and a current of .15 ampere gives a total resistance of 780 ohms. As the tube filament of 233+ ohms is in this total series, its resistance may be subtracted from the total or 780−233=547 ohms. Rather than use this *odd* value, a standard 545 ohm 15 watt resistor is used to provide the necessary voltage drop for operating the 35 volt filament direct from the power line. This takes care of the voltage distribution for the filament of the 35Z5 tube. You will soon see that the filament current for the other tubes is provided by the rectifier tube—a principle you have not heretofore studied in SAR lessons.

Referring again to Figs. 32 and 33, you will notice the peak limiting resistor R_{15} between terminals 3 and 5 of the 35Z5 tube. This resistor is so placed to limit *surges* and excessive current flow in the event of circuit element breakdowns or other failures. Notice that the plate is connected to the positive side of the power line. The cathode of the tube is positive also, but it is *less positive* than the plate. The proper line polarity is marked on the diagram and the re-

ceiver will function on D. C. *only when the power line plug is inserted in a socket with this polarity.* On A. C., of course, the rectifier will function *only* when the *cycle* polarity is the same as indicated on the diagram. During the *opposite* half of the A. C. cycle, the *filter condensers* provide the necessary current, as you have already learned. On D. C. operation, the rectifier (35Z5) will be continuously conductive and provide a D. C. output across C_{19}. On A. C. it will provide a pulsating D. C. across C_{19}. The filament supply filter circuit comprising C_{19}, R_{19} and C_{18} functions to remove line noises from a D. C. power source as well as *filtering* and smoothing the rectified D. C. from an A. C. power source. As will be described, resistor R_{19} is a voltage reducing resistor to provide proper *filament voltages* for the two 1N5, the 3Q5, the 1A7 and the 1H5 filaments.

Notice that the cathode of the rectifier is connected to *two* voltage divider networks and their loads. The second voltage divider is fed through resistor R_{16}. Condenser C_{16} filters this latter network. The divider network controlled by R_{19} can be easily traced by referring to Fig. 34 which omits the other network controlled by R_{16} in Fig. 33. The D. C. voltage at the output of the filter for R_{16} (across C_{16}) is about 90 volts. Therefore, the actual voltages applied to the receiver tube elements will be limited by circuit elements *or* limiting resistors according to the principles of ohm's law as explained in lesson ND-6. The *series* voltage distribution system is employed in the circuit of Fig. 32

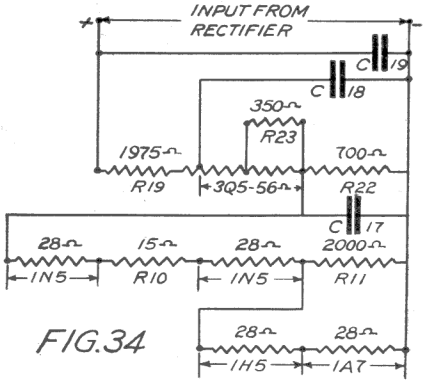


FIG. 34

rather than the shunt because it is *not* desirable to have a bleeder current drain when operating the receiver from dry batteries.

Condensers C_{19} and C_{16} are 40 mfd. 150 volt electrolytics. Condenser C_{18} is a 20 mfd. 50 volt electrolytic and C_{17} is a 200 mfd. 10 volt electrolytic. This extremely high capacity (C_{17}) is necessary to enable *storage* of the required filament current for use during the half cycle when the rectifier is *not* conductive. The required filament current in this case is .05 ampere or 50 milliamperes.

Several interesting and unusual problems arise when designing a receiver of this type. One such problem is the supply of *bias* voltages. The dashed lines of Fig. 33 indicate the various points to which the *grid* returns are connected. A good example of this method of bias supply is that provided for the 3Q5. Notice in Fig. 32 that the grid resistor R_{12} is connected between terminal number 7 of the 1H5 and the grid of the 3Q5. Referring to Fig. 33, you will see that the filament of the 3Q5 is the most positive in the series of filaments. Thus, its number 7 terminal, *relative to B minus*, is approx-

imately 5.6 volts as there are *four* 1.4 volt filaments between the 3Q5 and B negative. By connecting the 3Q5 grid load resistor to terminal 7 of the 1H5 a *more* negative voltage is obtained for the grid than would be obtained if the grid were returned to the filament of the 3Q5 tube. Its potential relative to B minus is approximately 1.4 volts. The difference between these two potnetials is 5.6 — 1.4 or 4.2 volts, which is the net bias voltage for the 3Q5 grid. In this case the filaments of the *two* 1N5's and the 1H5 function as a cathode resistor. The voltage drop across them being the bias voltage for the 3Q5. You may calculate the other bias voltages by the same process.

An exception in this circuit concerns the *delay* bias applied to the *diode* plate of the 1H5 which is a principle you will take up in detail in the lesson on automatic volume control.

In Fig. 32 you will notice the *bias cell* symbol to the right of C_{11}. The *positive* terminal of this *bias cell* is connected to terminal 7 of the 1H5. The negative terminal is connected to the junction between R_{12} and R_{13}. This *bias cell produces* a potential of 1 volt. As you will remember from your SAR lesson on detection, this diode is, then, insensitive to signals of less than 1 volt and is termed a delayed detector.

The bias cell is a very small acorn-shaped metal cup with a cover on one side of carbon. The potential developed between the metal cup and carbon electrode is caused by the chemical action of a third element inside the sealed cup. Though the potential is constant, these cells can only be used in grid circuits which *do not swing positive.* This is necessary because the cells will be ruined if allowed to discharge at a rate greater than 1 microampere. Otherwise the bias cells will last indefinitely.

The *automatic volume control bias* voltage for the signal grid of the 1A7 is supplied through filter resistor R_{13} *from* a variable D. C. established in R_{14} by the *rectified* signal. In this case, R_{14} is the *load* resistor for this diode detector section of the 1H5. A *negative* potential will be developed across this volume control (R_{14}) *relative* to the *filament* of the 1A7. This potential will be more negative for a strong signal and less negative for weaker signals. Automatic control of the C bias applied to the 1A7 is thus obtained accomplishing AVC, the details of which you will study in another lesson.

In calculating the resistor values for the series of filaments in the filter network comprising C_{19}, R_{19} and C_{18}, it is necessary first to know the number and voltage-curcent specifications of the tube to be operated. The filaments of the 1N5's, 1H5 and 1A7 are all rated at 1.4 volts and .05 ampere. The 3Q5 is rated at 2.8 volts and .05 ampere. Simple calculation will show that the resistances of the first four tube filaments will equal $\frac{1.4}{.05}$ or 28 ohms *each* and the 3Q5 filament is equal to $\frac{2.8}{.05}$ or 56 ohms.

A simplified diagram showing the voltage reducing resistors and filament resistances and their *series parallel* connections is shown

in Fig. 34. For the moment disregard R_{19}, R_{23} and the 3Q5 filament. This leaves *two* groups of parallel resistances to be calculated. Start with the 1H5 and 1A7 filaments. You will notice that these two resistances of 28 ohms *each* are *in series* giving a total of 56 ohms. This 56 ohm load is in parallel with R_{11} which is 2000 ohms. Here the formula $R=\frac{R_1 \times R_2}{R_1+R_2}$ may be used. Thus,

$$\frac{56\times2000}{56+2000}=\frac{112{,}000}{2056}=54.47+ \text{ ohms.}$$

This total parallel resistance of 54.47 ohms is in series with the *two* 1N5 filaments and R_{10}. These total 28+15+28+54.47 ohms or 125.47 ohms. As this group is in *parallel* with R22 of 700 ohms, the next portion of the problem becomes:

$$\frac{125.47\times700}{125.47+700}=\frac{85{,}500}{825}=103.6+$$

ohms (the .47 value may be dropped for convenience).

The actual effective value of R_{22} then becomes 103.6 ohms. The total load resistance is then R_{19} plus 103.6 plus the value of the 3Q5 filament with half of this filament shunted by R_{23}. The resistance of half of this filament is 28 ohms so

$$\frac{28\times350}{28+350}=\frac{9800}{378}=23+ \text{ ohms.}$$

There is, then, a total of 1975+28 +23+103.6 ohms or 2130 ohms (in round figures) across the output of the rectifier filter C_{19}. You may see in Fig 33 that if a larger current than .05 ampere were to pass through the unshunted portion of the 3Q5 filament it would burn out. Actually, there is *less* current than .05 ampere in this portion of the circuit. This is because the plate current *must* travel to the filaments from the B minus. As this total plate current amounts to 12 to 14 milliamperes and as 10 milliamperes of this total is used for plate current by the 3Q5, you can see that over 20% of the current required to heat the 1A7 filament will be the plate or cathode current of the other tubes. In the case of the 3Q5, notice that the shunted portion of the filament is the *most* negative of the two halves. In this tube, the filament is "V" shaped with the plate surrounding it on all sides. Because the shunted half is at a higher negative potential, there is a tendency for this half to *emit* a greater portion of the electron flow. On loud signal peaks this tendency would cause sputtering at spots on this half of the filament which could burn out the filament. Therefore, by shunting this half section by R_{23}, the temperature is lowered slightly. Thus, the two halves are made to emit more equally. The positions of R11 and R22 (shunt resistors) in this circuit are chosen to aid in equalizing the plate current distribution and to prevent it from rising to such high values that it added to the normal filament current, will not burn out the fragile tube filaments as a result of an overload.

The total resistance of 2139 ohms across the rectifier output is, then, required to carry approximately .045 ampere. Using the formula $E = I \times R$, $2130 \times .045 =$ 115.02 volts which may be the potential applied to the entire network. Considering the line voltage as 117 volts A. C., the potential applied to the *plate* of the rectifier will be about 110 volts. This

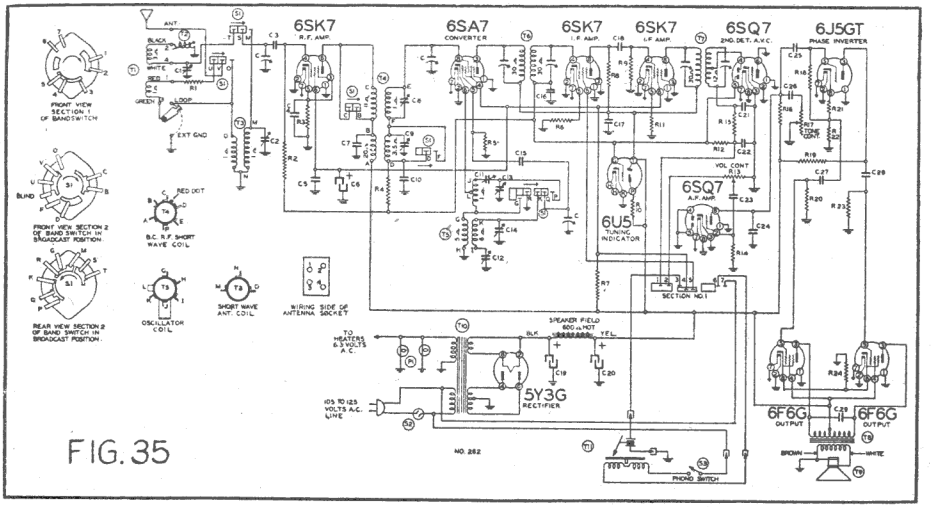


FIG. 35

is due to the voltage drop between terminals 2 and 3 of the 35Z5 which amounts to approximately 7 volts. There is about a 25 volt drop in the 35Z5; thus, 110−25= 85 volts. The actual A. C. peaks, as you know, are 1.414 times greater than this value. Multiplying 85 x 1.41 shows a peak value of 120.9 volts. This value will be lowered slightly, although, due to the use of a high capacity at the input of the filters, approximately the same value of D. C. will be obtained. Thus, a D. C. voltage of approximately 115 volts is supplied to the voltage divider network.

As this particular type of receiver circuit is extremently popular and prevalent, it is recommended that you study the foregoing analysis thoroughly.

By further tracing of this circuit, you may readily see how operation is allowed when S_2 is in the *battery* position.

Another type of voltage divider is shown in Fig. 35. This circuit makes use of a full wave rectifier. Thus, its most positive point will be terminal 2 (flament of the rectfier), and its most negative terminal will be the center tap to the high voltage winding on the power transformer. This, incidentally, would be true for all full wave rectifier circuits.

You will note the voltage divider network in Fig. 35 starts at the output of the filter or across condenser C20. The D.C. voltage across C20 is the same as it is from the rectifier filament to ground or B negative but minus the voltage drop across the 600 ohm speaker field. In other words, all rectified plate current flows thru the speaker field so the voltage at the output of the field winding is less than it is at its input. Thus, for purpose of analysis a simplified voltage divider network of Fig. 35 is shown in Fig. 36 with the assumption that the divider is connected across condenser C20 as shown in Fig. 35. Normal voltage at this point for this receiver is 250 volts D. C. and that is the value

used for the distribution network of Fig. 36.

It is necessary, when calculating the values of a circuit such as this, to allow for variations in manufacturing. For the resistors used in this circuit, the manufacturer has allowed a 10% plus or minus tolerance up to 12000 ohms. From 12000 to 2 megohms a 20% tolerance and from 2 megohms to 5 megohms a 30% tolerance. Thus, the actual value of voltages and currents in the circuit may be different than indicated or calculated. This is true in practice, and it is usual to allow a difference in voltage and currents of 10% *plus* or *minus*. As a basis for calculations, the actual bias potentials for the various tubes as stated by the receiver manufacturer are as follows:

6SK7—R. F. Amplifier	2.8
6SA7—Converter	0.0
6SK7—1st IF	3.3
6SK7—2nd IF	3.9
6J5—Phase Inverter	2.5
6SQ7—1st AF Amplifier	0.0
6U5—Tuning Indicator	0.0
6F6—PP Outut Tubes	17.5
6SQ7—2nd Det. AVC no bias —no D.C. plate potential.	

By referring to Fig. 36 you will notice the bias resistances for the first four tubes. The 6SK7 RF amplifier uses the *voltage drop* across R3 (300 ohms). Using the formula $I = \frac{E}{R}$ then $\frac{2.8}{300} = .007$ ampere. This is the *total cathode current* drawn by this tube. The tube characteristics state that with a plate voltage of 250 volts and a bias of —3 volts a plate current of .007 ampere and a screen current of .001 ampere will flow. These are standard rated values. Since in this case the grid voltage is less than 3 volts or 2.8 volts, the actual

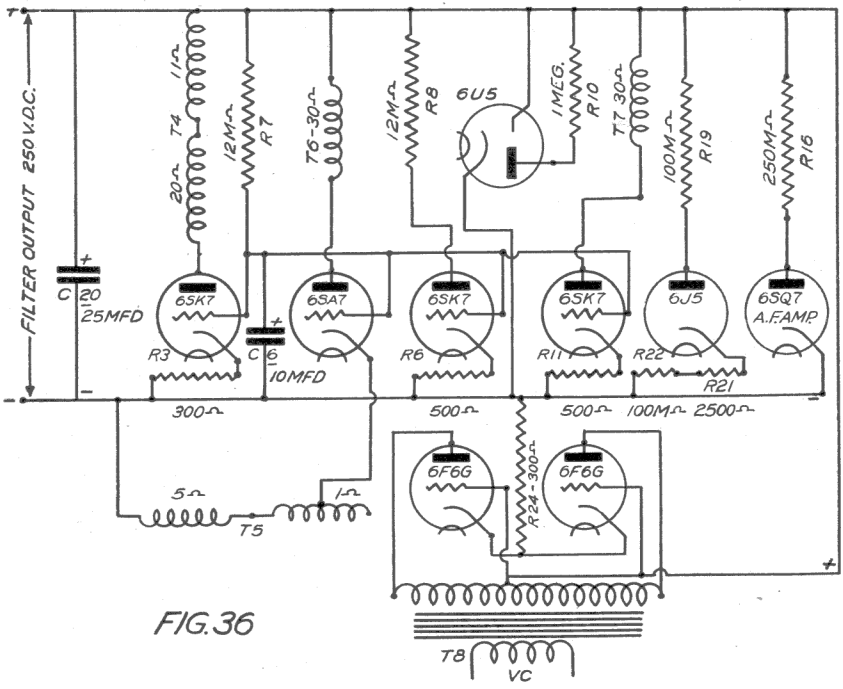


FIG. 36

	Bias	Plate Voltage	Plate Current	Screen Voltage	Screen Current	Cathode Current
RF 6SK7	−2.8	250	6.125 ma.	100	.875 ma.	7 ma.
Conv. 6SA7	0	250	3.40 ma.	100	8.00 ma.	11.4 ma.
1st IF 6SK7	3.3	250	5.75 ma.	100	.825 ma.	6.575 ma.
2nd IF 6SK7	3.3	180	5.75 ma.	100	.825 ma.	6.575 ma.
			21.025 ma.		10.525 ma.	31.550 ma.

current values will be different than rated values. Because of this, new values should be calculated for the plate and screen currents. Screen grid current for this tube is normally about 1/8 of the cathode current. The new plate current will be equal to 7/8 of the 7 milliamperes which gives .006125 ampere. The new screen grid current will equal 1/8 of .007 or .000875 ampere. This calculation is necessary in order to determine the value of the voltage drop across R7 which supplies the *screen* voltage for the *first four tubes*. The similar values for the three remaining tubes of this group can be caluculated in a like manner. Then the resultant screen currents should be added for the four tubes. With this total screen current you may then ascertain the voltage supplied to the screen grids or prove that the resistance value for R7 really should be 12,000 ohms.

The manufacturer's curve for the 6SA7 shows a screen current at 100 volts of .008 ampere and a plate current of 3.4 milliamperes with zero bias. As the D. C. resist ance of the two windings of T5 is only 5.5 ohms, in the cathode circuit, the bias is assumed to be zero, since there is little voltage drop across it. Almost the full 250 volts potential is applied to the plate since the resistance of T6, in this circuit, is only 30 ohms. In the 1st IF stage the bias of 3.3 volts across R6 (500 ohms) will result in a total cathode current of .0066 ampere. $I=\frac{R}{E}$ so $\frac{3.3}{500}=.0066$ ampere. Following the procedure used in the case of the RF tube, 8/8 =.0066 then 1/8=.000825 ampere. The plate current then equals 7/8 of .0066 or .00575 ampere with a screen current of .00825 ampere.

Reference to the characteristic curves for 6SK7 tubes show that to hold the *plate* current to this value (5.75 milliamperes) a plate voltage of 180 volts is necessary. This requires that there be a voltage drop across R8 of 70 volts. Since $R=\frac{E}{I}$ then $\frac{70}{5.75}=12.171+$ ohms. In this case, a 12,000 ohm resistor will do and is a standard value.

The same figures may be used for the 2nd IF tube as the bias resistor is also 500 ohms.

The table at the top of this page gives the total values for the various tubes.

The total cathode current may be assumed, for these four tubes, to be the sum of the screen and plate currents. Thus, 31.55 milliamperes is the total cathode current.

As a result of these calculations, it is possible to ascertain the voltage applied to the screen grids

through R7. The total calculated screen grid current is 10.525 ma. For convenience, this may be 11 ma. in round figures. Since $E = I \times R$ then the drop across R7 is equal to $12{,}000 \times .011$ or 132 volts. However, notice C6, which is a 10 mfd. electrolytic condenser. This condenser is across the screen grid circuit. There will be from 1 to 4 ma. drain caused by the polarizing or leakage current drawn by this condenser. This *leakage* current must be *added* to the total screen current. If this is assumed to be 1 ma. then $11 + 1 = 12$ ma. So $12{,}000 \times .012 = 144$ volts, which is the appropriate voltage drop across R7. The supply voltage is 250 volts so $250 - 144 = 106$ volts as the actual voltage applied to the screen grid circuit.

The 6J5 phase inverter presents a different situation. Note in Figs. 35 and 36 there are *two* resistors between B negative and the cathode. Note *also* that the grid return goes to the *junction* between these two resistors. Thus, *only the voltage drop across R21 is the actual bias* voltage. The manufacturer states that the bias voltage for this tube is 2.5 volts. As

$$I = \frac{E}{I} \text{ then } \frac{2.5}{2500} = .001 \text{ ma.}$$

which is the cathode or plate current for this tube. The circuit for this *phase* inverter is, in itself, a voltage divider and is illustrated in Fig. 37. The internal plate resistance (Rp) of the 6J5, under these conditions, is approximately 47,500 ohms. Adding the resistances in series across the voltage divider in Fig. 37 gives the following:

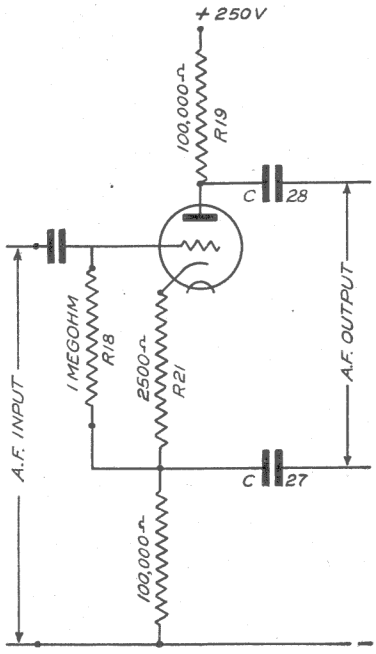


FIG. 37

100,000 (R22)
2,500 (R21)
47,500 (Rp)
100,000 (R19)

250,000 ohms.

At this point, it is interesting to notice that the output is taken from across the plate of the tube and R21. As these resistances (Rp and R21) total 50,000 ohms, this is 1/5th of the total series resistance. Hence, 1/5th of the AF *voltage* variations across this series will be fed to the push-pull stage. As each of the output voltages available at C27 and C28 *vary* with *respect* to the chassis and are approximately 180% out of phase, then these two voltages may be applied to the grids of the push-pull output tubes — this principle was explained in a previous lesson. The cathode circuit of the output stages will then act as the *center tap* of

an input transformer and an approximately equal AF voltage 180% out of phase will be applied to each of the output grids.

The resistor R10 of Figs. 35 and 36 is built *into* the socket employed to hold the 6U5 tube. (This type of tube will be explained later on in detail in another lesson).

These questions are desigend to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. How does the core of an efficient choke coil differ from that of a transformer?

No. 2. Describe briefly the function of an air-gap.

No. 3. How does the value of the filter input capacity affect the output voltage?

No. 4. What are the three functions a filter choke can perform all at the same time?

No. 5. Should filter choke coils be placed in the positive or negative high voltage lead of a filter circuit?

No. 6. If a speaker field is not tapped, how may it be arranged to supply bias voltages?

No. 7. Is the negative end of the complete voltage divider always grounded?

No. 8. What determines the value of a series voltage divider resistor?

No. 9. The total cathode current of a given tube is .012 ampere. The same tube requires a negative control grid voltage of 8 volts. What value should the cathode resistor have to provide for this voltage?

No. 10 The LC ratio of a given filter circuit is 192. If C has a value of 16 mfd. what should be the value of L in henries?